AD-A198 039

DTIC FILE COPY

(2)

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 88-0781
6a. NAME OF PERFORMING ORGANIZATION Purdue University; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NE
6c. ADDRESS (City, State, and ZIP Code) West Lafayette, IN 47907	7b. ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332-6448
8a. NAME OF FUNDING / SPONSORING AFOSR/NE; 8b. OFFICE SYMBOL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-85-0193
8c. Bldg 410 Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2305; TASK NO. C1; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Investigation of a New Concept in Semiconductor Microwave Oscillators

12. PERSONAL AUTHOR(S)
James A. Cooper, Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Annual	FROM 87/5/1 TO 88/4/30	88/5/31	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

The contiguous domain oscillator employs a two-dimensional electrostatic geometry to create conditions where a sequence of contiguous charge domains develop spontaneously in the channel region of an appropriately modified MESFET or MODFET device. These contiguous domains drift along the channel producing microwave oscillations in the drain current. Computer simulations indicate the device will be tunable over decades by control of the gate-to-source voltage.

The ITT Gallium Arsenide Technology Center in Roanoke, VA, has fabricated two 2-inch wafers of MESFET-compatible oscillator devices for our use. Each wafer contains several thousand devices, and initial screen indicates near 100% yield at DC test. We discovered a design oversight which produced an excessive gate-to-channel voltage drop when biased to the voltages necessary for microwave testing, resulting in immediate failure of the device under these conditions. By suitable reprocessing at Purdue, we have eliminated this problem and now have devices which can withstand DC biasing at the required fields. This means we can now operate the devices in the CW mode for microwave testing. (JES)

Initial microwave testing using a simple, non-optimized waveguide configuration has not given any indications of device oscillations. We are now re-examining our set-up to identify problems which might interfere with or obscure the effect. In particular, we have ordered a slide-screw tuner section for impedance matching and a waveguide phase shifter to allow us to match impedance and phase in the waveguide system.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Gerald L. Witt	22b. TELEPHONE (Include Area Code) (202) 767-4984; 22c. OFFICE SYMBOL AFOSR/NE

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

88 8 25 140

AFOSR-TR- 88-0781

Investigation of a New Concept in Semiconductor Microwave Oscillators

Annual Report

May 31, 1988

James A. Cooper, Jr.
School of Electrical Engineering
Purdue University
West Lafayette, IN 47907

Introduction

The Contiguous-Domain Oscillator is a bias-tunable, monolithically integrated, millimeter wave power source compatible with either the MESFET or MODFET technology. This novel oscillator device utilizes different electrostatic boundary conditions from any conventional microwave diode to achieve high frequency operation without the need for submicron dimensions or a tuned resonant cavity. At the start of this research program, this type of oscillator device was only a theoretical possibility, with all the performance information having been generated strictly by computer simulation. The objective of this research has been to fabricate and characterize experimental devices.

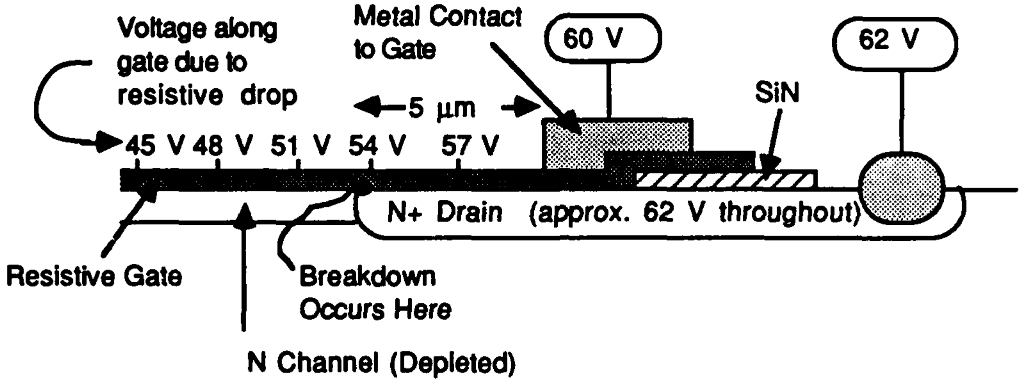
Device Fabrication

During the last three years, we have developed all the processing steps necessary to fabricate the MESFET version of the oscillator, including ion implantation, implant activation, and resistive gate deposition. We have now fabricated a total of six wafers of MESFET oscillators at Purdue. Not all of these wafers produced devices which were functional at DC test, but overall a total of thirty six functional devices were obtained from those six wafers. All thirty six devices were committed to microwave testing, but all of these devices failed immediately under the pulse biasing required to reach the threshold field.

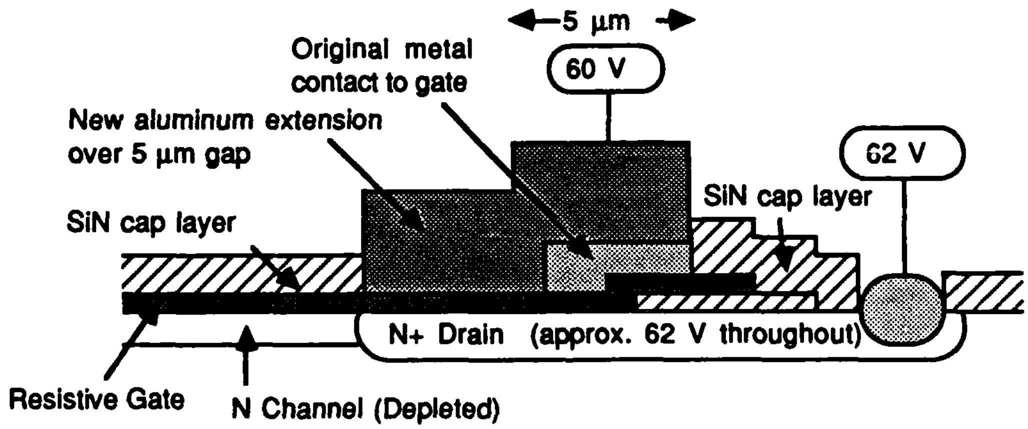
The potential of this oscillator concept was recognized by the ITT Gallium Arsenide Technology Center at Roakoke, VA. ITT suggested a collaboration which lead to their fabricating six two-inch wafers of the MESFET oscillators. Each of the six wafers had a slightly different channel depth and doping, to allow us to study the effects of these variations on performance. Two complete wafers and one partial wafer were delivered to our group on 23 February, 1988. We have concentrated our activities on the wafer which had channel doping and depth closest to the expected design optimum.

Initial DC testing of this wafer indicated nearly 100% functional yield. This means we have several thousand devices to use for microwave testing. The ITT devices also have a much larger gate resistance than our devices, which should result in lower power dissipation per unit area during the bias pulses. However, pulsed microwave testing still resulted in almost immediate failure of the ITT devices. The failure was nearly always manifest by a gate to drain short.

The failure under pulsed bias conditions was due to breakdown in the drain induced by the portion of the resistive gate which overlays the drain. This is illustrated in the diagram at the top of the next page. In order for the device to work, the ohmic contact to the resistive gate MUST lie over the drain, so that the electric field in the channel is uniform up to the edge of the drain region. The 5 µm spacing between ohmic contact and drain edge was introduced to allow alignment tolerance between the drain and contact masks. However, in operation the electric field in the gate is 1.2 V/µm, producing a potential drop of about 8 V between the gate and drain at the edge of the drain. This is in excess of the breakdown voltage of the heavily doped drain region. Once avalanche breakdown occurs, a gate-to-drain short is inevitable.



Fortunately, we have been able to rework the ITT devices to reduce or eliminate this overlap. The ITT devices are protected by a top layer of SiN. We first removed this nitride over the 5 µm gap using direct E-beam lithography (to insure precise alignment), then evaporated aluminum and lifted off the photoresist, leaving the structure shown below...

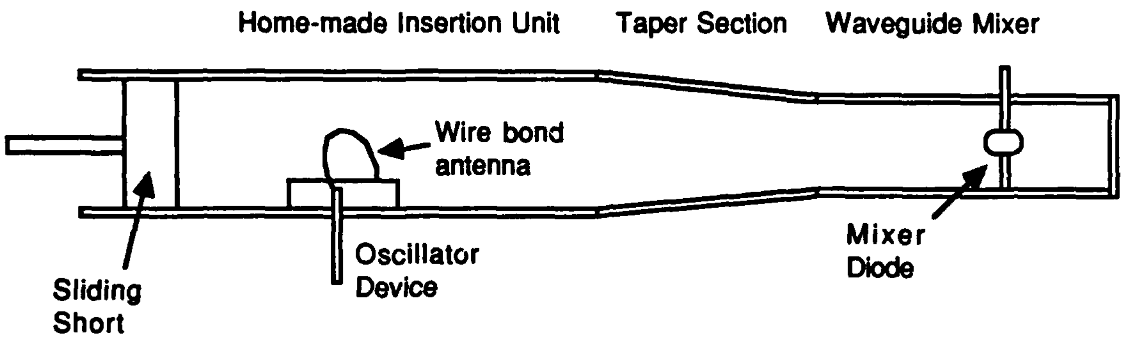


As seen, the 5 µm gap between the original gate contact and the left edge of the N+ drain region has now been shorted out by the new aluminum extension. As a result, the resistive gate remains at 60 V over the entire drain, and the gate-to-drain reverse bias is held to 2 V, well below breakdown.

We have processed a section of the wafer containing about eight chips using this procedure. Each chip contains 18 oscillator devices of various channel lengths and widths. At the time of this writing, we have demonstrated that the reprocessed devices <u>do in fact survive</u> the pulse biasing necessary for microwave testing. In fact, several of these devices survive continuous DC biasing at the desired fields, allowing us to dispense with the pulsing apparatus altogether. This simplifies the testing and should result in about a 50x larger signal to noise ratio on the spectrum analyzer.

Microwave Testing

Microwave testing of these reprocessed devices is just getting underway. The arrangement we are using consists of a home-made insertion unit in WR-28 band (26-40 GHz) connected through a taper section to a waveguide mixer in either WR-19 (40-60 GHz) or WR-12 (60-90 GHz) band, as shown below:



One of our concerns is that this arrangement essentially forms a resonant cavity, in spite of the fact that our oscillator device should be capable of operating into a nonresonant load. Therefore, in order for this arrangement to work, it is necessary that the following conditions be met: 1). the oscillator device should be an integral number of quarter wavelengths away from the sliding short, 2). the mixer diode should be an integral number of quarter wavelengths away from the fixed short at the end of the mixer, and 3). the oscillator and the mixer diode should be an integral number of half wavelengths apart. If these conditions are not met, microwave energy will not be coupled efficiently from the source to the detector. In addition, it is important that the impedance presented by the waveguide to the device and by the device to the waveguide be optimized for most efficient power transfer.

In order to address these issues and provide a means for optimizing the microwave system, we have ordered a slide-screw tuner and a waveguide phase shifter for WR-28 band. We will connect these elements between the insertion unit and the taper section. The slide-screw tuner consists of a finger or screw which penetrates into the waveguide. The screw introduces a reflection which can be used to null out reflections already present in the waveguide system. By adjusting the depth of penetration and the position along the guide, it is possible to present virtually any reactance to the device under test. The phase shifter can be used to adjust the electrical length of the waveguide, allowing us to vary the electrical separation between the oscillator and the mixer diode to achieve optimum coupling.

The length and orientation of the bonding wire "antenna" is also a concern. There are two possible orientations for this loop to excite the TE_{10} mode in the waveguide. One is in a plane perpendicular to the direction of propagation of the signals, with the wire located a quarter wavelength away from the sliding short. Another is in a plane parallel to the direction of propagation, with the wire located a half wavelength away from the sliding short. In the first of these, the loop should be located to one side of the centerline of the cavity, while in the second, the loop should be located along the centerline. We are presently mounting the device in the first configuration.

As we have said, this oscillator should be insensitive to microwave signals coupled to the drain lead. This is because the electrostatic conditions in the channel are determined by the voltage drop along the gate, and not by the drain voltage (so long as the drain is sufficiently positive to extract all electrons reaching it). However, the gate leads are sensitive to coupled microwave signals, since the gate establishes the field in the channel. Therefore, it is important to minimize coupling of microwave signals to the gate bonding wires.

There are several other measurement configurations which can be used — one possible arrangement is to operate the oscillator outside the waveguide, thereby avoiding the resonant structure entirely. We could then detect a signal by placing the mixer diode in close proximity to the device. These possibilities will be explored.

Since we have reached the phase of the project where sufficient devices are available to permit extensive microwave testing, it would be most helpful at this stage to have the assistance of a microwave expert. We will make every effort to find an appropriate person and to get this individual involved in an active way with this project.

Two-Dimensional Transient Computer Simulation

For the eighteen months we have been developing a two-dimensional transient computer simulation program specifically for the MESFET version of the device, the version which we are testing in the lab. A major stumbling block has been the strong nonlinearity in the velocity-field and diffusivity-field relations for electrons in GaAs. Initially it appeared that we could not use the Scharfetter-Gummel algorithm because of the failure of the Einstein relation at the fields of interest. However, early this year we were able to manipulate the equations into a form consistent with Scharfetter-Gummel, and as a result we have been able to speed up the simulation by a large factor. In addition, the code is fully vectorized for execution on vector supercomputers like the Cray, the Cyber 205, or the Gould NP-1.

We have verified the computer code for calculation of steady state conditions by comparing the predictions with those published by Alan D. Sutherland [Report No: ECOM-75-1344-F] for silicon MOSFETs. These comparisons have been made for a 3 μm MOSFET operated under four biasing conditions: weak inversion triode, weak inversion saturation, strong inversion triode, and strong inversion saturation.

We are now testing the code on simple transient situations. Our initial test case is a drifting charge packet in an otherwise depleted silicon MOSFET. Since the transient simulation is essentially a sequence of steady state calculations separated by a small time step (typically 10 fs or less, with the desired simulation time typically around 10-25 ps), the overhead in computer time is enormous (estimates run into the tens of hours of CPU time). The transient code is now running on a Gould NP-1 computer as a "friendly user" while the machine is undergoing acceptance testing and software development. It remains to be seen whether the code can be optimized sufficiently to allow us to solve the oscillator in a reasonable amount of time.

Summary

After three years work, we now have devices which survive DC biasing to the voltages needed to place the channel in the regime of negative differential mobility. We are now entering a phase of the project which may require several months (or longer): the microwave testing of these devices.

Because of the high frequencies involved (20 to 100 GHz), and the fact that these devices are monolithically integrated in a planar geometry, the proper mounting to efficiently couple the microwave signal into the waveguide will require considerable experimentation. We now have the basic microwave equipment (325 GHz spectrum analyzer, microwave insertion unit, etc.) necessary to perform this work. However, experience suggests that this phase will be far from straightforward. We obviously hope to demonstrate microwave oscillation quickly, but unforeseen complications cannot be ruled out.

If thorough testing in a variety of configurations fails to produce evidence of oscillation, we will consider fabricating the MODFET version of the oscillator. The MODFET version does not allow significant vertical rearrangement of the charge domains, as does the MESFET version. Without this vertical degree of freedom, the charge in the channel may be more likely to form domains. The computer simulations we have performed to date have all assumed that the channel charge was confined to a thin sheet, and so technically represent the MODFET version of the oscillator rather than the MESFET version. (A full two-dimensional computer model for the MESFET version is under development.)

The novel oscillator device investigated in this project utilizes different electrostatic boundary conditions from any conventional microwave diode to achieve high frequency operation without the need for submicron dimensions or a tuned resonant cavity. The potential benefits of a bias-tunable, monolithically integrated, MESFET or MODFET compatible millimeter wave power source will be enormous.